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Effects of Mineral Nutrient Levels on the Inorganic Composition and Growth of Corn (*Zea mays* L.)

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INTRODUCTION

The amount of each mineral nutrient in the growth media is one of the most important factors which may alter the inorganic composition and growth of plants. Varying the concentration of one nutrient element in the growth media will have a pronounced effect on the concentration of another nutrient in the plant. Various plant nutrient interactions are well known and documented for many plant species (4, 5, 7, 8, 14, 18, 20, 21, 22, 23, 26).

Even with the vast amount of information available regarding the various plant nutrient interactions, most studies have been directed toward effects of only a few nutrients on a few other nutrients. These studies do not show the effects of various levels of the many mineral nutrients on the uptake and accumulation of the many other mineral nutrients. Information of this type needs to be collected by using one plant species and with plants grown under the same environmental conditions. Limitations in analytical instruments and procedures are primary reasons why this information has been limited. Recent advances and developments in the emission spectograph and the atomic absorption spectrophotometer have made these complex studies more suitable.

The purpose of this study was to determine the effects that various levels of NH_4-N, NO_3-N, K, P, Ca, Mg, S, Mn, Fe, B, Cu, and Zn had on the growth and the content of N, K, P, Ca, Mg, S, Mn, Fe, B, Cu, and Zn in corn plants grown under the same environmental conditions.

MATERIALS AND METHODS

Growth of Plants

Four 7- to 10-day-old corn (Ohio W64) seedlings, germinated in silica sand, were transferred without seeds to 1-gallon plastic pots containing half-strength nutrient solutions. The plants were supported by small sections of plastic tubing extending through the lid. Figure 1 shows a sample of the plants grown for 14 days in nutrient solutions. Solutions were aerated by glass capillaries extending into the nutrient solution and connected to a central air hose by hypodermic needles.

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FIG. 1.—Example of corn plants grown for 14 days in nutrient solutions at five levels of a mineral nutrient. (Magnesium was varied in this experiment.)

Plants were grown in a growth chamber under conditions of 8 hours of darkness at 18° C. and 16 hours of light at 200 ft.-c. and 24° C.

The composition of the nutrient solutions is given in Table 1. Varying degrees of deficiency for each mineral nutrient were attained by decreasing the concentration of one nutrient while keeping the other nutrients constant at full strength. Five levels of each nutrient were added to the solutions as treatments: full, 1/10, 1/50, 1/200, and zero strength. In the mineral-deficient solutions, $Ca(H_2PO_4)_2$ replaced the K salts in K deficiencies; NH_4NO_3, $Mg(NO_3)_2$, $CuCl_2$, and $ZnCl_2$ replaced the SO_4 salts in S deficiencies; KNO_3 replaced the Ca and PO_4 salts in Ca and P deficiencies; K_2SO_4 replaced ammonium salts in NH_4-N deficiencies; and $CaCl_2$ replaced nitrate in NO_3-N deficiencies.

Macronutrient salts and iron citrate, used in all micronutrient deficiency studies, were purified of contaminating heavy metals. This was accomplished by shaking aqueous solutions of the salts with 0.20% diphenylthiocarbazone in chloroform. The solutions were washed repeatedly with chloroform until excess diphenylthiocarbazone was removed. Excess chloroform was removed from the solutions by heating. All salts were made to volume and stored at 4° or —15° C. to eliminate microbe growth.

The seedlings were grown in half-strength nutrient solutions for the first 3 or 4 days before being introduced to full-strength solutions. Seedlings transferred directly to full-strength solutions grew slower initially than those placed in half-strength solutions. Water and iron were added as needed.

TABLE 1.—Concentration of Salts Used for Full-Strength Nutrient Solutions.*

Salt	mMoles/liter
$CaCl_2$	1.30
$Ca(NO_3)_2$	3.20
$(NH_4)_2SO_4$	0.76
KH_2PO_4	0.72
KCl	2.21
$MgSO_4$	1.25
Fe Citrate	0.27
	uMoles/liter
H_3BO_3	23.12
$MnCl_2$	4.57
$ZnSO_4$	0.76
$CuSO_4$	0.32
H_2MoO_4	0.14

*See text for salts omitted or added for mineral-deficient solutions.

The plants were grown in solution cultures for 14 to 15 days before the experiment was terminated. Available growth chamber space limited the number of plants which could be grown at one time and therefore treatments were replicated at different times. Three replications were made for all of the nutrient deficiencies except Ca, B, and NO_3-N deficiencies, which were replicated twice.

The four plants of each pot were combined and the roots were detached, rinsed, and washed for 5 minutes in 1 N HC1. Both the tops and roots were rinsed thoroughly with glass-distilled water before being blotted dry. The plants were air-dried at 65° C. in a forced-air oven, weighed, and ground to pass a 40-mesh screen for inorganic analyses.

Inorganic Analyses

Duplicate samples were analyzed for nitrogen by the Kjeldahl method, for S by a modified turbidometric method of Bulters and Chenery (6), for Mg by atomic absorption spectrophotometry, and for the other nutrient elements by emission spectroscopy.

Samples analyzed by emission spectroscopy were prepared by ashing a given dry weight sample for 4 hours at 500° C. An aliquot of 0.68 M $LiCO_3$ was added as an internal standard to each sample at a ratio of 5.0 ml. standard to 1.0 g. dry wt. plant sample. The samples were mixed thoroughly and analyzed by a direct reading Jarrell-Ash (Model 66-000) spectrograph.

For S and Mg analyses, 0.1 g. samples were digested in 5 ml. 15.6 M HNO_3 plus 1 ml. 11.6 M $HC1O_4$ over low heat until the solution was clear. The solutions were evaporated to dryness on a steam plate before the dried material was suspended in a small amount of dilute HC1 and diluted to 25.0 ml. in water. Aliquot samples were removed for Mg determinations and the remainder was used for S analysis.

RESULTS AND DISCUSSION

Visual deficiency symptoms appeared within 3 to 7 days after deficiency treatments were administered. Good plant growth was attained for plants grown in non-deficient solutions. Growth decreased, however, as the nutrients became deficient (Figure 1 and Table 2). Greater decreases in dry weights were noted at the higher nutrient levels (1/50 strength and above) for NH_4-N, NO_3-N, K, P, Mg, and Mn and at the lower nutrient levels (1/50 strength and below) for Ca, S, Fe, Cu, and Zn. Reductions in growth of 62, 44, 25, 23, and 21 percent were noted for Mn, K, Fe, Mg, and NO_3-N-deficient plants, respectively, between full and 1/10 strength solutions.

Growth reductions at the most severe level of each mineral deficiency followed the given sequence: K $>$ Mn $\geq$ Mg $\geq$ Ca $>$ P $>$ S $>$ Zn $>$ NO_3-N $\geq$ Fe $>$ NH_4-N $\geq$ Cu. In the case of Cu, Fe, and Zn-defici-

TABLE 2.—Effects of Mineral Deficiencies on the Dry Weights of Corn Plants.

Nutrient Level	Deficiency											
	NH_4-N	NO_3-N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Ratio to Non-Deficient (Full-Strength)											
Full*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1/10	0.87	0.79	0.56	0.75	1.11	0.77	0.98	0.38	1.01	0.92	1.10	1.10
1/50	0.80	0.57	0.29	0.41	0.85	0.48	0.51	0.27	1.02	1.02	1.03	1.11
1/200	0.81	0.64	0.25	0.35	0.49	0.32	0.41	0.25	0.90	1.13	1.13	0.58
0	0.76	0.61	0.20	0.34	0.30	0.29	0.38	0.27	0.63	1.02	0.78	0.57
	g. dry wt./plant											
Full	2.55	2.54	2.41	1.91	2.40	3.15	3.69	2.86	2.55	2.96	2.57	2.36

*Full-strength solutions were non-deficient solutions.

ent plants, the contents of the nutrient in solution were very low before decreases in growth occurred. Linear decreases in growth were noted for NH_4-N, NO_3-N, K, P, Ca, and S-deficient plants in solutions of 1/10 strength or less. A linear decrease in growth for Mg-deficient plants was noted in solutions of 1/50 strength and below. Under the conditions of these experiments, the amount of K, Ca, Mg, P, S, and Mn required to reduce growth 50% was calculated to be 7.4, 1.1, 0.8, 0.9, 1.2, and 0.005 mg./1., respectively.

Regardless of the B level, no growth reductions were noted. Boron contents of the plants decreased as the level added to the nutrient solution decreased but adequate B was still present to give optimum growth. Since very low amounts of B are required for the growth of young corn plants (9, 15), different procedures and equipment or a longer growth time may be required before induction of true B deficiencies may be accomplished.

Changes in the nutrient content of the plants noted henceforth were significant at the 0.10 level or higher.

Increased K and decreased P were noted in the plants as NH_4-N deficiency increased (Table 3). The greatest change in the nutrient contents of the plants was between the full and 1/10 strength NH_4-N solutions. The greatest effect of increased NO_3-N deficiency on the nutrient content of the plants was found between the full-strength and 1/10 strength solution treatments (Table 4). Total N in the plant decreased significantly (40%) between these two levels and decreased only slightly below 1/10 strength NO_3-N. Contents of K, Ca, Mg, Mn, Cu, and Zn decreased in the plants as NO_3-N deficiency increased.

Reasons why an NH_4-N deficiency had little effect on total N of the plant might be considered. Less NH_4-N from the solution may be required inside the plants since NO_3^- can be converted to NH_4^+ via nitrate reductase. Decreased growth due to the absence or depletion of NH_4^+ inside the plant would not be expected unless the formation of NH_4^+ from nitrate reductase in the plant was insufficient to supply the needs of the plant. The decreased growth because of lack of NH_4^+ may also suggest an NH_4^+ requirement by corn plants.

Explanations why decreased growth and N contents of the plant resulted because of increased NO_3-N deficiencies might also be considered. Corn plants may have a NO_3^- requirement which cannot be substituted by NH_4^+. The high NH_4^+ contents could possibly exclude further absorption of NH_4^+ by the roots. This exclusion might cause a decreased N content of the plant. At high concentrations, NH_4^+ could also compete with other cations such as K^+, Ca^{2+}, and Mg^{2+} for absorption sites to a point where these ions may be limiting. It is known that

TABLE 3.—Mineral Nutrient Content of Corn Leaves as Ammonium-Nitrogen Varied in the Nutrient Solutions.

NH_4-N Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.26	4.91	0.90	1.00	0.47	0.36	75	311	17	14	47
1/10	3.00	6.42	0.71	0.91	0.36	0.36	86	134	13	11	45
1/50	2.84	7.13	0.68	0.89	0.36	0.29	88	120	14	11	46
1/200	2.79	6.43	0.66	0.85	0.34	0.30	71	122	13	10	44
0	2.94	7.63	0.66	0.83	0.35	0.31	72	134	14	10	43
Standard Error	0.166	0.385	0.032	0.071	0.051	0.019	6.8	54.2	1.2	0.8	2.3

TABLE 4.—Mineral Nutrient Content of Corn Leaves as Nitrate-Nitrogen Varied in Nutrient Solutions.

NO_3-N Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.55	5.01	0.93	1.00	0.41	0.37	54	202	18	13	33
1/10	2.12	4.75	1.04	0.41	0.20	0.40	19	236	14	11	20
1/50	1.84	4.68	0.95	0.32	0.16	0.28	14	197	14	10	19
1/200	1.95	4.99	0.88	0.39	0.18	0.34	22	205	14	10	20
0	2.04	4.52	1.02	0.32	0.18	0.38	19	309	16	10	21
Standard Error	0.074	0.138	0.049	0.071	0.022	0.038	5.3	23.1	0.5	0.3	1.4

NH_4^+ competes with K^+ (11,13,26), which could conceivably reduce the K^+ content of the plant. The data of Table 4 suggest that K^+ was not limiting; however, Ca^{2+}, Mg^{2+}, and Mn^{2+} were considerably lower in the plants. The Mn concentration noted for NO_3-N-deficient plants was at a level which also caused a deficiency in Mn-deficient solutions.

Decreasing the level of K in the solution culture yielded decreased levels of K in the plants, while the plant content of the other nutrient elements, except Cu, increased (Table 5). The greatest changes in plant composition of macronutrient elements and Fe was between full-strength and 1/10 strength K solutions, while the greatest change for the micronutrient elements was in solutions of 1/50 strength or lower. Increased Ca and Mg deficiencies resulted in slightly decreased N and increased P, B, Cu, and Zn in the plant (Tables 6 and 7). Slight increases in plant contents of S, Mg, and Mn and a slight decrease of K were also noted in Ca-deficient plants. The contents of S, Ca, and K increased as Mg deficiencies increased in the plants.

Decreased P in the nutrient solution brought about decreased K but increased Mg, Fe, B, and Zn in the plant (Table 8). Slight increases in Ca and Cu were also noted. Increasing S deficiencies resulted in increased N, P, B, and Cu and decreased Ca, Mg, Mn, and Fe (Table 9). When Mn was omitted from solutions, Ca and Mg decreased in the plants and B, Cu, Zn, and P increased (Table 10). Increased Fe deficiencies increased K, P, S, Mn, and Zn in the plants (Table 11). B deficiencies had essentially no effect on the nutrient content of the plants (Table 12). Copper-deficient plants contained lower Ca and higher S (Table 13). P, Fe, B, and Cu increased in the plants as Zn was omitted from the solution (Table 14).

Many antagonistic and synergistic effects of a particular nutrient on another nutrient or nutrients in plants are widely recognized and reported. Of particular prominence are the reciprocal relationships between the base elements K, Ca, and Mg (1,8,10,13,22,26). Interactions between the anionic and the cationic nutrients (1,13,17,19,22, 26), the macroelement and micronutrient elements (8,13,24), the non-essential and the essential elements (3,17,25), and other mineral combinations are also widely recognized. Each interaction may not exist under all conditions at any given time, since factors such as plant species and variety or line (5,12), plant part, stage of growth, properties and composition of the growth media (22), etc., may alter or control the manifestation of interactions.

Table 15 summarizes the significant pattern modifications of the nutrient element contents in corn plants with each nutrient deficiency. Some of the interactions noted are not new. On the other hand, others are not clearly understood or little information regarding them has been reported. This is especially true with the interactions involving S, B, and some of the micronutrients. Many other nutrient trends were noted but they were not significant at the 0.10 level.

It is generally recognized that the sum of the cations and the anions in plants tends to be fairly constant (2,10,16,26). That is, the $\frac{\text{meq cations}}{\text{meq anions}}$ per unit weight of plant material is equal to a constant. The cations would consist primarily of K^+, Mg^{2+}, Ca^{2+}, NH_4^+, and Na^+, while the anions would consist primarily of NO_3^-, PO_4^{3-}, SO_4^{2-}, Cl^-, and organic acids. Ammonium ions should contribute very little to the total cation content, since the majority of them would be metabolized into amine or amide nitrogen. Sodium was not added to the solutions and therefore it would have no effect on cation value. The micronutrient elements are present but their quantities are too small to add any significance to the cation or anion values. Therefore, the total cation content of the plant would consist almost entirely of Ca^{2+}, Mg^{2+}, and K^+.

The cation contents of the plants for each nutrient level are given in Table 16. These values, calculated by the method of Munson (16), show the relative constancy of the cation equivalents in the plants over all the ranges of each mineral deficiency. Slight increases in the cation contents were noted for NH_4 and Fe-deficient plants. As K, Mg, or Ca became limiting, other cations substituted for the deficient element to keep the cation value constant.

The relative constancy of the anion equivalents of the plants could not be assessed because the Cl content of the plants was not determined. The anions would be expected to remain constant since chemical reactions take place on equivalent bases. Anion nutrients (NO_3^-, PO_4^{3-}, SO_4^{2-}, and Cl^-) compensating for other anion nutrients are not quite the same as for cations. Organic acids partially replace the anion nutrients inside the plant and help maintain the electrostatic balance between cations and anions.

Decreased cation contents were noted as the anion nutrients (NO_3-N, P, and S) decreased in the nutrient solutions. Higher accumulations of organic acids in NO_3-N, P, and S-deficient plants were not noted (unpublished data). If higher organic acid values had been noted, it might be suggested that organic acids had compensated for the loss of the anion nutrients. If complete compensation of organic acids for anion nutrients had occurred, the cation contents probably would not have decreased.

TABLE 5.—Mineral Nutrient Content of Corn Leaves as Potassium Varied in the Nutrient Solutions.

K Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.55	4.95	1.30	0.89	0.33	0.33	50	224	16	14	39
1/10	4.02	1.38	2.18	2.09	0.88	0.39	118	466	34	16	72
1/50	4.19	1.00	2.45	2.02	0.68	0.33	77	716	36	13	78
1/200	4.14	0.83	2.60	2.06	0.70	0.30	93	550	48	13	98
0	4.06	1.25	2.85	2.24	0.77	0.49	92	585	51	15	92
Standard Error	0.286	0.200	0.257	0.190	0.099	0.061	15.0	148.1	6.0	1.2	13.5

TABLE 6.—Mineral Nutrient Content of Corn Leaves as Calcium Varied in the Nutrient Solutions.

Ca Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	4.31	7.42	1.45	0.62	0.15	0.26	48	244	14	11	40
1/10	4.03	8.05	1.28	0.23	0.23	0.26	69	280	16	10	41
1/50	3.91	8.69	1.24	0.18	0.34	0.32	100	164	14	11	47
1/200	4.11	7.22	2.41	0.06	0.36	0.38	108	430	21	22	82
0	3.94	6.84	3.18	0.05	0.32	0.32	81	1029	27	24	89
Standard Error	0.350	0.303	0.231	0.081	0.055	0.013	13.2	55.1	5.0	2.1	9.0

TABLE 7.—Mineral Nutrient Content of Corn Leaves as Magnesium Varied in the Nutrient Solutions.

Mg Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.64	4.52	0.81	1.00	0.37	0.29	59	323	24	15	39
1/10	3.73	5.95	1.10	0.97	0.12	0.23	67	438	20	16	57
1/50	3.19	5.93	1.74	0.77	0.08	0.19	86	252	21	19	62
1/200	3.21	5.59	2.06	0.89	0.07	0.21	96	350	22	20	81
0	2.95	5.91	1.73	0.79	0.07	0.19	86	252	30	20	84
Standard Error	0.137	0.390	0.168	0.056	0.230	0.015	12.9	120.3	1.9	0.8	6.6

TABLE 8.—Mineral Nutrient Content of Corn Leaves as Phosphorus Varied in the Nutrient Solutions.

P Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.64	6.46	1.26	0.76	0.26	0.30	44	405	16	14	41
1/10	3.38	5.25	0.26	0.66	0.30	.034	21	1451	18	14	35
1/50	3.48	4.27	0.40	0.74	0.38	0.54	30	1416	26	22	49
1/200	3.07	4.64	0.27	0.76	0.36	0.33	37	1903	27	21	61
0	3.20	4.71	0.44	1.05	0.47	0.37	38	1968	37	21	72
Standard Error	0.253	0.425	0.193	0.106	0.036	0.086	8.2	293.7	4.5	3.4	4.4

TABLE 9.—Mineral Nutrient Content of Corn Leaves as Sulfur Varied in the Nutrient Solutions.

S Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	4.24	3.92	0.75	0.88	0.62	0.30	51	515	30	14	42
1/10	3.55	3.41	0.75	0.59	0.44	0.12	55	269	21	13	36
1/50	4.66	3.97	1.42	0.52	0.37	0.08	40	215	24	16	45
1/200	5.06	3.72	1.64	0.56	0.39	0.05	35	195	24	17	43
0	4.88	3.70	1.47	0.52	0.39	0.05	36	184	28	17	43
Standard Error	0.270	0.216	0.081	0.036	0.033	0.020	2.5	35.7	1.8	0.7	0.9

TABLE 10.—Mineral Nutrient Content of Corn Leaves as Manganese Varied in the Nutrient Solutions.

Mn Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	4.26	5.11	0.82	0.91	0.43	0.41	39	285	24	15	46
1/10	4.41	7.96	1.66	0.84	0.37	0.38	14	214	28	22	62
1/50	4.25	6.20	1.66	0.83	0.35	0.44	11	198	27	22	59
1/200	3.84	7.31	1.54	0.68	0.31	0.38	15	243	30	20	53
0	4.27	6.54	1.74	0.76	0.35	0.39	11	218	28	22	68
Standard Error	0.262	0.903	0.198	0.044	0.024	0.042	3.8	58.9	1.1	1.4	4.3

TABLE 11.—Mineral Nutrient Content of Corn Leaves as Iron Varied in the Nutrient Solutions.

Fe Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.66	4.26	0.64	1.25	0.37	0.26	64	118	12	12	42
1/10	3.58	5.46	1.02	1.13	0.40	0.27	71	101	14	12	50
1/50	3.60	5.84	1.08	1.07	0.40	0.28	74	82	12	12	53
1/200	3.61	6.07	1.25	1.10	0.43	0.30	87	75	14	14	58
0	4.12	7.36	1.48	1.08	0.32	0.40	97	63	14	14	67
Standard Error	0.179	0.600	0.152	0.112	0.043	0.029	7.8	7.6	1.4	0.9	2.7

TABLE 12.—Mineral Nutrient Content of Corn Leaves as Boron Varied in the Nutrient Solutions.

B Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.32	4.74	0.79	1.08	0.46	0.26	75	116	20	12	40
1/10	3.96	6.79	1.13	1.18	0.42	0.28	93	198	12	14	44
1/50	3.54	4.78	0.88	1.16	0.47	0.25	75	132	9	13	35
1/200	3.14	5.05	0.86	1.20	0.51	0.23	75	112	7	12	36
0	3.34	5.05	0.92	1.22	0.50	0.25	78	147	8	13	39
Standard Error	0.209	0.480	0.078	0.078	0.023	0.017	7.1	16.1	2.3	1.0	2.5

TABLE 13.—Mineral Nutrient Content of Corn Leaves as Copper Varied in the Nutrient Solutions.

Cu Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.80	5.54	0.82	1.14	0.36	0.20	68	476	13	14	68
1/10	3.62	5.09	0.82	1.14	0.39	0.20	73	190	13	11	85
1/50	3.90	5.52	0.87	1.16	0.37	0.28	63	233	13	9	60
1/200	3.61	4.82	0.71	1.03	0.42	0.26	57	367	12	8	58
0	3.87	5.97	0.82	1.02	0.39	0.30	63	238	14	7	87
Standard Error	0.301	0.384	0.080	0.020	0.021	0.017	8.7	98.5	0.2	0.9	11.8

TABLE 14.—Mineral Nutrient Content of Corn Leaves as Zinc Varied in the Nutrient Solutions.

Zn Level	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Percent						ppm				
Full	3.99	5.76	0.93	1.16	0.44	0.38	77	190	16	14	62
1/10	3.72	5.52	1.19	1.09	0.38	0.38	93	473	21	15	22
1/50	3.99	6.88	1.73	1.11	0.41	0.46	109	1038	27	16	17
1/200	4.02	6.56	2.24	1.18	0.35	0.47	109	1542	26	19	18
0	4.05	6.99	2.46	1.23	0.41	0.37	115	1813	33	21	19
Standard Error	0.284	0.526	0.096	0.097	0.024	0.051	23.1	282.0	2.4	1.8	9.3

TABLE 15.—Modifications of Nutrient Element Contents in Corn Leaves as Each Nutrient Varied in the Nutrient Solution.*

Nutrient Varied	Nutrient Content of Leaf										
	N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
NH_4-N		+++	---			-				-	
NO_3-N	---			---	---		--		--	---	---
K		---	++	+++	++		+		++		+
P		--	--		++			++	+		+++
Ca		--	+++	--		+++		+++		+++	++
Mg	--	+	+++	-	---	---			+	+++	+++
S	++		+++	---	---	---	---	---	--	++	
Mn			+	--	-		---		+	+	+
Fe		+	++			++	+	-			+++
B									-		
Cu				---		++				--	
Zn			++					++	+++	+	--

*Significance at the .10, .05, and .01 levels for — or +, —— or ++, and ——— or +++, respectively. The minus marks (—) refer to decreases and the plus marks (+) refer to increases in nutrient content compared to non deficient (full strength) plants.

TABLE 16.—Cation Equivalents of Mineral Deficient Corn Plants.*

Nutrient Level	Deficiency											
	NH_4-N	NO_3-N	K	P	Ca	Mg	S	Mn	Fe	B	Cu	Zn
	Ratio to Non-Deficient (Full-Strength											
Full	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1 00
1/10	1.12	0.75	1.07	0.86	1.01	1.07	0.78	1.31	1.13	1.25	0.96	0.94
1/50	1.20	0.70	0.92	0.79	1.11	1.01	0.79	1.09	1.17	1.03	1.00	1.10
1/200	1.10	0.76	0.92	0.83	0.93	0.98	0.81	1.17	1.21	1.08	0.92	1.06
0	1.24	0.69	1.05	0.94	0.88	1.00	0.78	1.11	1.33	1.08	1.04	1.14
	meq cations/100 g. dry wt.											
Full	214	212	198	224	233	196	195	210	202	213	228	241

*The cation equivalents were calculated from K^+, Ca^{2+}, and Mg^{2+} only.

SUMMARY

Corn plants were grown in a growth chamber in nutrient solutions containing five levels of NH_4-N, NO_3-N, K, P, Ca, Mg, S, Mn, Fe, B, Cu, and Zn. Plant growth and leaf contents of N, K, P, Ca, Mg, S, Mn, Fe, B, Cu, and Zn were determined for each nutrient level.

Numerous changes in the mineral content of the leaves and interactions of the various nutrients were observed as many nutrients became deficient in nutrient solutions. Deficiencies of NO_3-N, P, and S decreased the cation equivalents of the plants, but Fe and NH_4-N-deficient plants contained slightly higher cation equivalents. Dry weights of the plants decreased for all mineral deficiencies except B. Growth reduction at the most severe level of each mineral deficiency followed the given sequence: K $>$ Mn $\geq$ Mg $\geq$ Ca $>$ P $>$ S $>$ Zn $>$ NO_3-N $\geq$ Fe $>$ NH_4-N $\geq$ Cu.

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